

URBAN CITY PLANNING IN SEMI-IMMERSIVE VIRTUAL REALITY SYSTEMS

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Abstract: Virtual reality based geographic information systems (VRGIS) have been successfully employed for urban planning and architectural design in recent years. Tracking technologies and stereoscopic visualization of three-dimensional structures allow a better insight into complex datasets. Unfortunately, these systems often lack intuitive interaction concepts and therefore reduce VRGIS to advanced visualization environments, since manipulation of the content is not or only rudimentarily possible. In this paper, we present a geographic information system for urban planning tasks in semi-immersive virtual reality (VR) systems. The objective of this approach is to provide professional city planners with an enhanced VR interface, which enables comfortable interaction concepts similar to the interactions of the real-world planning task. To assure the usability and relevance of the developed system, urban planners have cooperated closely in the development process. In this paper both the hard- and software architecture of the entire system as well as VR related interaction metaphors and their evaluation are discussed.

1 INTRODUCTION

Urban planning tasks are of major importance for civil works since both the environment and the inhabitants of a city are affected. The cityscape as well as the quality of life of the residents essentially depend on the appearance of buildings, road networks, planting, green spaces, and recreation areas such as parks and playgrounds. To facilitate a realistic impression of how a building area would visually integrate into the environment and to enable communication regarding development proposals, it is important to present intermediate results of the planning process properly as well as comprehensible.

Therefore, by using two-dimensional CAD concepts urban planners design development plans for a certain area based on existing cadastral data, which is available for every town in Germany. As depicted in Figure 1 (left) cadastral data usually contains building footprints, number of floors and floor's height for each building, parcel boundaries, and other information. Within such a development plan, urban planners define entities, for example buildings and recreation areas, associated with a set of constraints, which specify what types of geobjects are allowed and what re-

quirements have to be incorporated. After urban planners have agreed to a certain development plan, two different procedures are commonly used.

One approach is to deliver the development plan to an architectural office. On the basis of this plan architects generate virtual 3D models and return exemplary three-dimensional visualizations of these planned areas to the urban planner. This procedure has the following two major shortcomings. First, the returned visualizations are static insofar as the 3D models cannot be explored interactively by the urban planners. Second, modifications to the 3D models, which, for instance, have been proposed after reviewing the 3D visualization, cannot be performed by urban planners. Instead, the architectural office has to be asked again to incorporate these modifications into the 3D model. During a planning task, this usually takes several iterations resulting in inefficiency as well as unnecessary expense.

The second common alternative to communicate urban development proposals is to build a physical block model usually made of wood, plastic or paper. Figure 1 (right) illustrates such a physical block model for the development plan in Figure 1 (left). After a physical block model has been finished, per-

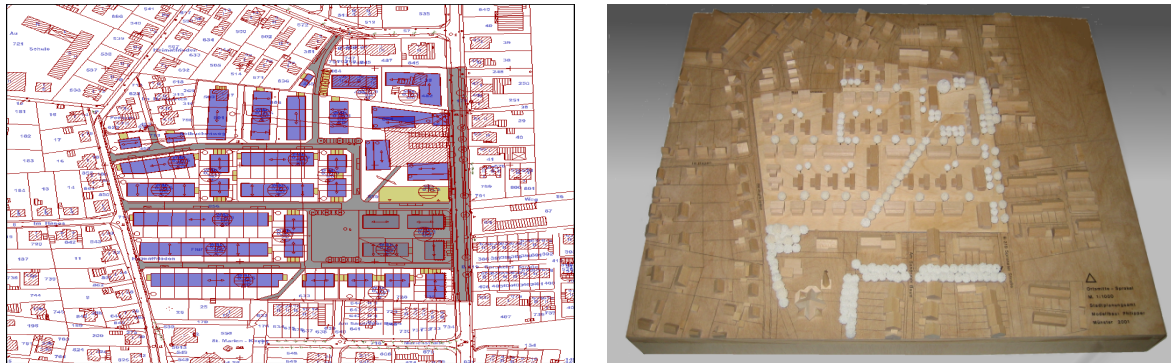


Figure 1: Example section of an urban development plan within cadastral information (left) and a corresponding physical block model made of wood downscaled to 1:1000 (right).

forming modifications is often awkward, since most elements are inflexible and fixated to the model, so that they have to be removed and replaced by new elements. Furthermore, the creation of these models is a very time consuming task, which requires high efforts in terms of money and manpower. Thus, simpler solutions to visualize planned development areas are desired.

In cooperation with the urban development, city planning and transport planning office as well as the land surveying and land registry office of the city of Münster in Germany, we have developed solutions for these problems. An objective of this cooperation is to develop computer-aided concepts, which serve the needs of professional urban planners and provide a convenient alternative to current planning tasks. Urban planners demand that the developed strategies should be based on their current processes resulting in physical block models as well as computer generated 3D visualizations. However, the city planners desire to have more independent and sophisticated control over both approaches; they want to be able to generate virtual 3D city models and create three-dimensional visualizations autonomously. Furthermore, the intuitive comprehension when viewing a physical block model should be obtained.

In consideration of these two major demands, we decided to develop an interactive 3D residential city planning software system, which runs in *virtual reality* (VR) systems as well as in desktop-based environments. To ensure the adaptation of the planning system into already existing systems and databases, a *geographic information system* (GIS) interface has been integrated to import the required data. Virtual reality based geographic information systems (VR-GIS) are increasingly used for planning tasks, since VR technologies provide better perception and comprehension of complex 3D structures (Beck, 2003). Unfortunately, these systems often lack intuitive interaction concepts and therefore VRGIS are degraded to

exploration systems (Dodge et al., 1998; Beck, 2003). In order to enhance the interaction in VRGIS we have developed intuitive interaction metaphors which facilitate the efficient design of building plans in a highly-interactive way.

In this paper, we present the system architecture and setup of the 3D residential city planning system. In particular, we propose advanced concepts for generic interaction tasks, whose benefits have been proven in usability studies. The paper is structured as follows. In Section 2 the table-top-based VR system and its benefits are discussed. In Section 3 the architecture of the interactive 3D residential city planning software is explained in detail. In Section 4 concepts which facilitate an intuitive interaction within both VR systems as well as desktop environments are proposed and their evaluation is discussed. Section 5 concludes the paper and gives an overview of future research directions.

2 SEMI-IMMERSIVE VIRTUAL REALITY SETUP

Since professional urban planners desire to maintain intuitive comprehension obtained when viewing a physical block model, we have chosen a semi-immersive RWB environment in combination with an optical tracking system to visualize interactive virtual 3D city models. In comparison to physical block models, the usage of such a VR system setup enables an improved interaction with potential building plans, because interactive modification, e.g., texturing and altering of building parameters, can be incorporated. The components of the VR system are explained in the next subsections.

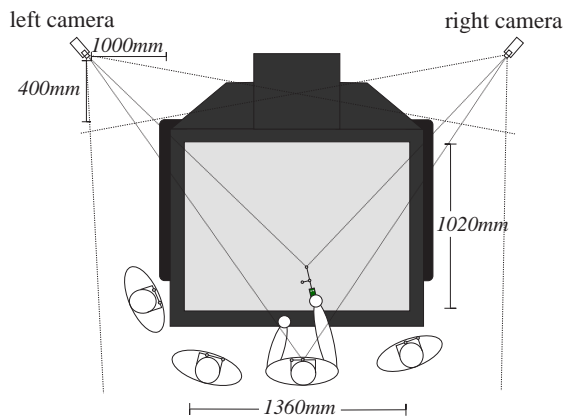


Figure 2: Conceptual view of the semi-immersive RWB. Two cameras track the area in front of the RWB, where four users collaborate (adapted from (Dorfmueller-Ulhaas, 2002)).

2.1 Responsive Workbench

A Barco BARON responsive workbench (RWB) (Krüger et al., 1995), is used to present 3D city models stereoscopically in a way that enables urban planners to work in an environment they are accustomed to. The horizontal or tilted workspace of the RWB is a well known table-top metaphor many professionals are familiar with (see Figure 2). The images are projected onto the display's surface so that planners perceive virtual 3D models as being attached to the surface (see Figure 3 (right) and Figure 5). This is due to the fact that the images are rendered stereoscopically with negative parallax. The images are displayed in sequence and are synchronized with active shutter glasses the professional urban planners have to wear. The stereo glasses are transparent, therefore real-world objects such as the RWB and input devices can be seen and users are semi-immersed into the virtual world.

The workbench is about $2m \times 2m$ large and $1.2m$ high. The display screen measures $1.36m \times 1.02m$ with a maximum pixel resolution of 1280×1024 . The maximum refresh rate of $120Hz$ is ensured with a resolution of 1024×768 pixels, which supports comfortable working without flickering effects. As illustrated in Figure 2 the size and resolution of the workbench allows several planners to view virtual 3D models in a stereoscopic projection. City planners can walk around the RWB in order to view the virtual 3D city model from different perspectives. To enable such an exploration from multiple view positions, the system must be aware of the user's current position, which determines the virtual camera's position and orientation accordingly. For this purpose tracking systems are used.

2.2 Tracking System

High accuracy and wireless interaction is indispensable for precise and comfortable urban planning, therefore an optical tracking system is used to determine the position of the planners as well as their input devices. The accuracy of the stereo-based optical tracking systems is in the range of submillimeters, and thus tracking errors are minor and precise interactions with objects displayed on the RWB are possible. Since lighting conditions around the RWB have to be darkened because the brightness of the projection itself is limited, *infrared* (IR) light in combination with IR-filters is used. The operation area of the tracking system is determined by the physical measures of the workbench, a volume of about $3m \times 3m \times 1.5m$ has to be scanned. To enable an optimal tracking of this area two cameras are arranged above and beside the workbench as depicted in Figure 2. unit Because of the many drawbacks of IR-LEDs, we have decided to use passive markers to be tracked by the system. These markers are made of small spheres covered with reflective material, so that light emitted by an IR-spot, which is positioned close to the camera lens, is reflected back to the camera. Only the reflected IR light of the markers passes through a filter, which is attached to the front of the lens. With corresponding tracking algorithms (Dorfmueller-Ulhaas, 2002) the position of each marker and thus the position and orientation of unique rigid body arrangements of such markers can be determined.

2.3 Input Devices

Passive marker tracking provides more flexibility in comparison to other technologies, e.g., electronic or magnetic approaches. Attaching certain devices with a unique rigid body arrangement of at least three markers results in arbitrary 6 degrees of freedom (DoF) input devices, i.e., devices whose position and orientation can be tracked. However, further input events such as button events and gestures are required to manipulate a development plan. For this purpose, we have equipped urban planners with Fakespace pinch data gloves, which provide a gesture-based recognition system. Furthermore, we use a haptic input device, which supports planning by vibration feedback. In combination with acoustic signals this information can be used to give feedback about invalid interactions, e.g., collisions between virtual buildings during the planning process. This device is equipped with two input buttons, passive markers and the vibration unit, which enables transmission of haptic signals with different intervals. The buttons can be used similar to the buttons of a standard mouse, e.g., the left button for selection tasks, the right button to open 3D context menus.

3 3D RESIDENTIAL CITY PLANNER

The objective of the 3D residential city planning application is to provide urban planners an intuitive and natural interface to plan and modify residential areas within desktop- and VR-based system environments. In the following sections the architecture and main components of this system are introduced.

3.1 Architecture

During the development phase of the application, city planners express their desire for flexible approaches for the visualization of generated virtual 3D city models. Although photorealistic rendering is important, it is not the only requirement; especially non-photorealistic rendering supports to comprehend structures and relations similar to view physical block models. Furthermore, during exploration interactive frame rates are more important than photorealistic appearance. However, realistic visualizations similar to the renderings provided by architectural offices are desired.

Due to these demands, we have chosen *VRS*, the *Virtual Rendering System* (Döllner and Hinrichs, 2002), as core graphics library for building 3D city models. *VRS* is an object-oriented and scenegraph based C++ graphics library. It introduces the usage of two different graphs. *Geometry graphs*, which store the visual appearance of virtual objects collected in scene nodes, are combined with *behavior graphs* to represent their behavior in terms of interaction and animation. Different renderings are ensured with this library, since *VRS* provides wrapping classes to photorealistic renderers, such as *POVRay* or *Radiance*, but also real-time renderers, e.g., *OpenGL*, are supported. Changing the used rendering system without the need for modification of an application's source code. Furthermore, *VRS* is extensible to a VR software system by using the *Virtual Reality VRS (VR²S)* component (Steinicke et al., 2005a), which handles all VR related issues.

3.2 Main Components

The 3D residential city planner consists of four conceptual components:

1. **Converter tool:** The converter tool parses and converts the cadastral data into a scenegraph structure, which is used to represent the corresponding geodata.
2. **Geobject model:** The geobject model is the collection of geobjects and their properties. This model is generated during the parser process of the converter tool. Components of this model are buildings, building and traffic areas, trees etc.
3. **Visualization component:** This component constructs the scenegraph representing the topological structure of the city model. Each scene node in the geometry graph representing a collection of geobjects is associated with a visual appearance, e.g., by assigning colors or textures.
4. **Interaction component:** The interaction component manages required interactions with virtual 3D city models. A graphical user interface (GUI) based on *wxWidgets* allows to access certain interactions. Alternatively, direct interaction concepts such as arrangement of virtual buildings are incorporated.

The converter tool parses the cadastral data and generates a scenegraph data structure containing the corresponding geodata. Since the cadastral data is geo-referenced, virtual 3D city models can be generated automatically. Because there is no overall accepted standard for storing cadastral information, we have developed an interface which provides the required generality and flexibility to enable import of cadastral data from different sources. For instance, for the city of Münster the cadastral data stores building footprints, number of floors, parcel boundaries and other information in Gauß-Krüger coordinates, which are converted during the reconstruction process. Based on this information the system generates a geo-referenced virtual 3D city model of the surrounding area, which is superimposed with aerial photographs to provide more realism and higher recognition.

Within the geobject model all geobjects are aggregated in the class *CityModel*, which administers all required information for a geo-referenced city model. Instances of type *GeoObject* provide the base from which all geobjects, for example instances of type *Building* or *ParcelArea*, inherit. An instance of the class *Building* consists of one or more *BuildingParts* for handling different types of stories and roofs. The other geobjects are organized analogously.

The visualization component is separated from the geobject model of the virtual city. All required information to visualize the objects of an instance of the class *GeoObject* is handled via the class *AppearanceManager*. The visual appearance of each geobject can be assigned randomly, or the city planner can define the appearance, for example by assigning specific textures to each geobject. As mentioned above *VRS* uses a scenegraph to represent virtual scenes. Since generated virtual 3D city models may consist of over 50,000 complex, textured geobjects, it is not recommend to store each of these geobjects in corresponding scene nodes, because

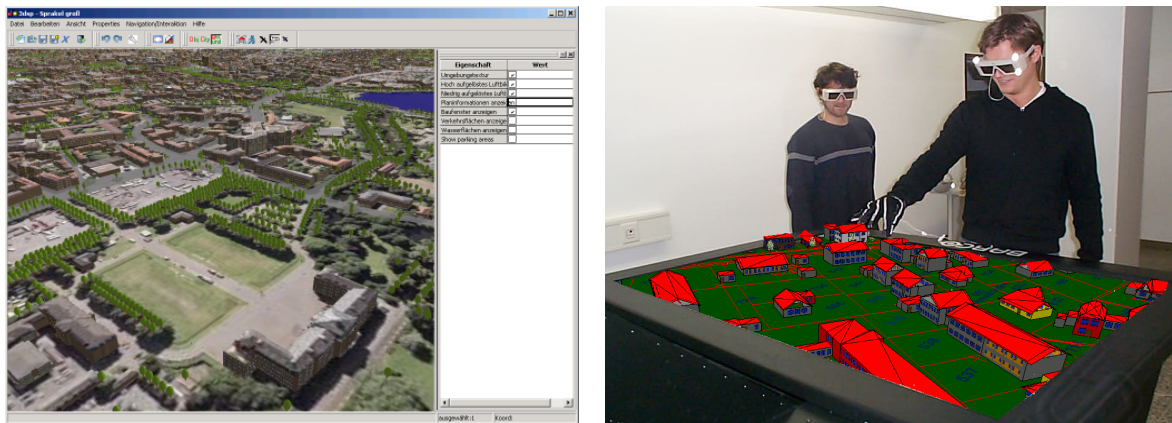


Figure 3: Example photorealistic visualization of a generated 3D city model within the GUI (left) and NPR of the cadastral data shown in Figure 1 on the workbench (right).

this would inflate memory requirements for storing the scenegraph and decrease performance when evaluating it. Due to the wrapping mechanism of VRS it is possible to store these enormous datasets with renderer specific optimization strategies.

To assist the city planners during the design process the graphical representation of both the cadastral plan as well as the building plan can be projected onto the virtual 3D city model (see Figure 3 (right)). To further increase performance, optional view-dependent level-of-detail algorithms are integrated to enable switching between different levels of realism. Furthermore, it is possible to switch between non-photorealistic and photorealistic rendering.

Besides the standard menu-based interaction concepts, such as creation, arrangement or deletion of virtual buildings, different navigation and traveling metaphors can be chosen via menu entries. These exploration metaphors as well as arrangement of geoobjects can be performed in a direct way without using the menu. These techniques include *flying*, *gliding*, *walking* and *ufo-viewing* metaphors, i.e., an exploration with orthogonal view onto the city model. When exploring a city model, arbitrary locations can be stored as *visual bookmarks* to be accessed later on, for example to generate smooth camera motions along a resulting path.

When working in desktop-base environments, professional city planners have to handle 3D interactions with 2D input devices, e.g., the standard mouse. To reduce the cognitive effort for such 3D interactions, we have integrated *3D widgets* (Döllner and Hinrichs, 1998) into the manipulation process. 3D widgets provide an easy way to manipulate objects with 6 DoF by reducing the simultaneously manipulated DoF to one degree. 3D widgets provide handles for translation, rotation, and scaling of virtual geoobjects. Thus,

these manipulation tasks can be performed as easily as in two-dimensions. However, as illustrated in Figure 5, 3D widgets can also be used in VR.

4 VIRTUAL REALITY INTERACTION CONCEPTS

As mentioned above VRGIS environments lack intuitive interaction concepts. In this section VR-based interaction metaphors integrated in the 3D residential city planner are introduced. These generic interaction tasks include exploration concepts for collaborative interaction in the RWB environment and advanced manipulation strategies to design, explore and communicate virtual 3D development plans.

4.1 Collaborative Exploration

When designing a development plan, often several urban planners with different background, i.e., expertise and knowledge, are involved. Such cooperations have been proven to be advantageous since the bundling of expert's knowledge has the potential to increase productivity. Consequently, it is desirable to develop virtual environments simulating such shared space in which collaboration can be performed as easily and naturally as in the real world.

Although the described semi-immersive RWB system provides enough space to enable several planners to interact in a collaborative way, the teamworking process is constrained due to the shortcoming that usually only one user is head-tracked and thus perceives a fully perspective-correct stereoscopic image. Hardware-based solutions to this problem involve reduction of the refresh rate (Agrawala et al., 1997).

Because of physical constraints, these approaches are hard to scale. Hence, we have developed a software-based collaboration environment that allows several city planners to work together in the RWB environment. The only requirement to enable such a collaboration is that each planner who wants to participate in the collaboration process has to wear tracked glasses so that the planners' head positions can be determined. Therefore, all input devices and tracked glasses have to be registered by the tracking system. If this prerequisite is fulfilled, group activity can be performed by using two different strategies:

1. **Cooperative interaction mode**, i.e., tasks are accomplished consecutively. For example, one city planner modifies the development plan and afterwards a second planner continues the work.
2. **Split-screen collaboration mode**, i.e., users collaborate simultaneously. For example, one city planner creates virtual buildings and provides them to another planner who arranges them on a building area.

In both modes *active planners*, i.e., currently interacting urban planners, perceive a perspective-correct stereoscopic image either on the entire projection screen or in different viewports on a tiled screen. Before any cooperative or collaborative interaction can be started potential participants need to register. Registration can be performed by miscellaneous strategies, e.g., posing gestures or using speech commands. When an urban planner has registered for the cooperation and this registration has been accepted, e.g., an active planner or administrator confirms the registration by gestures, this registered planner gets active, i.e., his head and input devices are tracked and used for the interaction. In the case of the cooperative interaction mode, the registered urban planner switches the state from a passive planner, who only observes the scene, to the active planner and the previous active planner gets passive. When a registration process of an urban planner has been accepted in the split-screen collaboration mode, the screen is tiled so that the additional active collaborator is assigned his own viewport, whereas the viewports of other active collaborators are scaled down accordingly. Each active collaborator perceives perspective-correct stereoscopic images in his viewport, therefore interactions can be performed comfortably.

The introduced concepts allow city planners to communicate and work together in a very natural way. A typical planning situation benefiting from the collaborative interaction mode divides the work into two subprocesses. One urban planner creates virtual buildings via the GUI by defining building footprints, heights, roof types and textures etc., while a second city planner arranges these buildings in the development plan. Hence, planning processes can be accel-



Figure 4: Two users collaborating in the a tiled viewport arrangement.

erated and optimized since several planners can combine their knowledge and abilities. In Figure 4 the 3D residential city planning software runs in a two-user split collaboration mode, in which both planners perceive perspective-correct stereoscopic images.

4.2 Manipulation

The concepts described in Section 4.1 enable several urban planners to explore virtual 3D city models. The aforementioned typical situation in which two planners collaborate, e.g., the first urban planner creates virtual buildings, while the second planner arranges them, involves many problems when using current manipulation metaphors. While GUI-based interaction, for instance, generating buildings can be performed very comfortably in desktop-based environments or on a personal-interaction-panel in VR (Szalavári and Gervautz, 1997), 6 DoF manipulations of these virtual buildings are often complicated. Although VR environments provide the possibility to manipulate virtual objects in an intuitive manner, e.g., by using a *virtual hand* or a *virtual pointer* (Mine, 1995), these concepts are often constrained, because in VR the cognitive effort for a city planner is definitely higher than the corresponding effort in the real world. In addition, it is often difficult to perform precise interactions because of tracking errors and hand tremors. For example, it is hard to select small resp. distant objects or items, e.g., the described handles of 3D widgets, with a virtual pointer or virtual hand in VR. Hence, generic interaction tasks need to be enhanced. In order to achieve this goal we propose the *improved virtual pointer* (IVP) metaphor, which avoids most of the aforementioned disadvantages of current interaction metaphors (Steinicke et al., 2005b). This approach allows the city planner to select a desired geobject or item with a virtual pointer without requiring an exact hit. While a straight ray is used to indicate the direction of the virtual pointer, an additionally visualized bendable ray points to the closest selectable geobject (see Figure 5). The

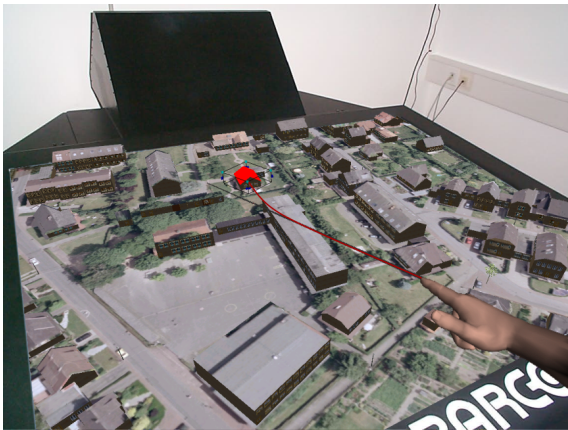


Figure 5: Virtual 3D city model and improved virtual pointer as seen from a city planner's view.

closest selectable geobject which would be chosen if the city planner would perform a selection, e.g., by pressing a button or by pinching a glove, is called *active geobject*. Since this geobject is determined in a pre-evaluation phase of the scenegraph with simple geometric calculations, this results in almost no performance loss. After selecting the active geobject, manipulations can be performed similar to the manipulations of physical block models. The movements of the virtual input device are transferred by a scaled one-to-one mapping to the selected geobject, which supports also the manipulation of distant objects. Due to this mapping strategy virtual geobjects can be arranged very comfortably and intuitively.

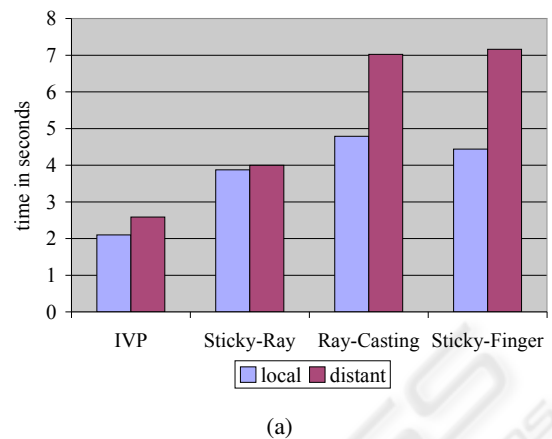
4.3 Evaluation

In this section the evaluation of the concepts described in Section 4.1 and Section 4.2 is discussed.

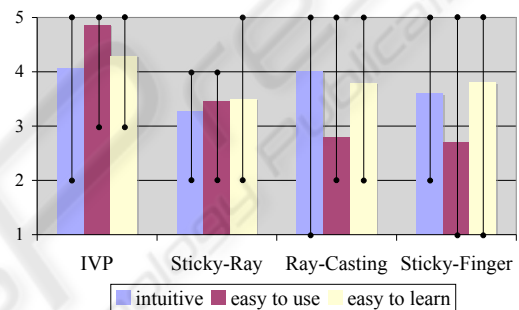
The subjects chosen for the test series were familiar with residential planning environments. Most subjects were geoinformatic students, but also landscape ecologists, computer scientists and mathematicians participated in the usability study.

4.3.1 Evaluation of Exploration Concepts

We have tested both proposed cooperative and collaborative interaction modes for usability in a preliminary user study with 7 participants. The participants were equipped with tracked shutter glasses and pinch gloves for the registration process. Registration had to be initiated by simple gestures combined with acoustic feedback giving an indication which user wanted to participate in the collaboration and which user was currently active. Up to three participants had to explore virtual 3D city models simultaneously by



(a)



(b)

Figure 6: Results of the usability study.

using the described concepts. Afterwards, they were asked to evaluate the proposed strategies in a user survey. The results of this survey show that a decreasing projection size, when splitting the screen into two or three subviewports, has not disturbed the collaborators in terms of limited space or distraction of other planners' viewports. Furthermore, the space in front of the RWB has been evaluated as large enough for collaborative interactions. The participants considered the required gestures for the registration process as intuitive and easy to learn. Furthermore, the users evaluated the usage of multimodal feedback, which supports the users during the interaction, in particular during the registration process, as very helpful.

4.3.2 Evaluation of Manipulation Concepts

We have evaluated the manipulation concepts in a usability study with 15 participants. During the test series the subjects had to accomplish several selection and positioning tasks, i.e., randomly marked virtual buildings had to be selected and arranged in a devel-

opment plan by using different interaction metaphors. These metaphors included the IVP metaphor and a simplification, called *sticky-ray metaphor*, the *ray-casting technique*, and the *sticky-finger technique* described in (Steinicke et al., 2005b; Bowman and Hodges, 1997; Pierce et al., 1997). We have evaluated the time needed for each subtask and the accuracy achieved with a certain metaphor. The most significant result is illustrated in Figure 6 (a). This state-chart shows the time needed for a selection subtask when using the different metaphors. The results clearly show that the IVP metaphor improves efficiency and that selections are performed faster for local object selection, i.e., selection in the immediate reach of the user, as well as for distant geobjects. Furthermore, performing manipulations was more accurate and precise using the described IVP metaphor.

After the user study the participants have had to evaluate the metaphors in a five-point Likert scaled survey (from 1 to 5 associated with corresponding ratings). Figure 6 (b) underlines that the participants have evaluated the IVP metaphor as the most intuitive, ease to use and easy to learn metaphor in comparison to the other approaches.

Furthermore, we support the interaction with multimodal feedback. For example, when a selection is possible, e.g., the selection ray hits a virtual building, the users perceive a slight vibration and an acoustic feedback. The intensity of both signals depend on the position of the virtual building with respect to the participant's position. Although in several surveys participants have evaluated these concepts of multimodality as very helpful, the usage of multimodal feedback did not increase efficiency. However, the participants felt convenient and confirmed during interaction processes when receiving multimodal feedback.

5 CONCLUSION AND FUTURE DIRECTIONS

We have proposed a 3D residential city planning application for semi-immersive VR systems. Due to the fact that this system has been developed with cooperation partners from the domain of urban planning, their demands could be fulfilled so that they are motivated to use the application to develop new building plans. The user studies have proven the usability and benefits of the proposed concepts.

Currently, the land surveying and land registry office evaluate a prerelease version and the urban development, city planning and transport planning office will test the software system in a real planning process soon. When these field studies are finished, modifications of the actual application or integration

of further functions will be accomplished.

REFERENCES

- Agrawala, M., Beers, A., Fröhlich, B., Klimetzek, F., and Bolas, M. (1997). The Two-User Responsive Workbench: Support for Collaboration through Individual Views of Shared Space. In *ACM Proceedings of Computer Graphics and Interactive Techniques*, pages 327 – 332.
- Beck, M. (2003). Real-Time Visualization of big 3D City Models. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXIV(5/W10).
- Bowman, D. and Hodges, L. (1997). An Evaluation of Techniques for Grabbing and Manipulating Remote Objects in Immersive Virtual Environments. In *ACM Symposium on Interactive 3D Graphics*, pages 35–38.
- Dodge, M., Doyle, S., Smith, A., and Fleetwood, S. (1998). Towards the Virtual City: VR & Internet GIS for Urban Planning. In *Workshop on Virtual Reality and Geographical Information Systems*.
- Döllner, J. and Hinrichs, K. (1998). Interactive, Animated 3D Widgets. In *Computer Graphics International 1998*, pages 278–286.
- Döllner, J. and Hinrichs, K. (2002). A Generic Rendering System. *IEEE Transaction on Visualization and Computer Graphics*, 8(2):99–118.
- Dorfmüller-Ulhaas, K. (2002). *Optical Tracking - From User Motion to 3D Interaction*. PhD thesis, Technische Universität Wien.
- Krüger, W., Bohn, C., Fröhlich, B., Schuth, H., Strauss, W., and Wesche, G. (1995). The Responsive Workbench: A Virtual Work Environment. *IEEE Computer*, 28(8):42–48.
- Mine, M. (1995). Virtual Environments Interaction Techniques. Technical Report TR95-018, UNC Chapel Hill Computer Science.
- Pierce, J., Forsberg, A., Conway, M., Hong, S., Zeleznik, R., and Mine, M. (1997). Image Plane Interaction Techniques in 3D Immersive Environments. In *ACM Symposium on Interactive 3D Graphics*, pages 39–44.
- Steinicke, F., Ropinski, T., and Hinrichs, K. (2005a). A Generic Virtual Reality Software System's Architecture and Application. In *Proceedings of the 15th International Conference on Artificial Reality and Telexistence (ICAT05)*.
- Steinicke, F., Ropinski, T., and Hinrichs, K. (2005b). Multimodal Interaction Metaphors for Manipulation of Distant Objects in Immersive Virtual Environments. In *13th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision*, pages 45–48.
- Szalavári, Z. and Gervautz, M. (1997). Using the Personal Interaction Panel for 3D Interaction. In *Proceedings of the Conference on Latest Results in Information Technology*, page 36.